

WHAT IS CLAIMED IS:

- 1 1. An apparatus for measuring blood oxygenation in a subject, said apparatus
2 comprising:
3 a first signal source which applies a first input signal during a first time
4 interval;
5 a second signal source which applies a second input signal during a second
6 time interval;
7 a detector which detects a first parametric signal responsive to said first
8 input signal passing through a portion of said subject having blood therein and
9 which detects a second parametric signal responsive to said second input signal
10 passing through said portion of said subject, said detector generating a detector
11 output signal responsive to said first and second parametric signals; and
12 a signal processor which receives said detector output signal, said signal
13 processor demodulating said detector output signal by applying a first
14 demodulation signal to a signal responsive to said detector output signal to
15 generate a first output signal responsive to said first parametric signal and applying
16 a second demodulation signal to said signal responsive to said detector output
17 signal to generate a second output signal responsive to said second parametric
18 signal, each of said first demodulation signal and said second demodulation signal
19 comprising at least a first component having a first frequency and a first amplitude
20 and a second component having a second frequency and a second amplitude, said
21 second frequency being a harmonic of said first frequency, said second amplitude
22 selected to be related to said first amplitude to minimize crosstalk from said first
23 parametric signal to said second output signal and to minimize crosstalk from said
24 second parametric signal to said first output signal.
- 1 2. The method of Claim 1, wherein the second amplitude is determined by
2 turning off one of the first and second signal sources and measuring the crosstalk between
3 one of the parametric signals and the non-corresponding output signal while varying the
4 second amplitude and selecting a second amplitude which minimizes the measured
5 crosstalk.

3. A method of minimizing crosstalk between two signals generated by applying a first pulse and a second pulse to measure a parameter, wherein said first pulse and said second pulse are applied periodically at a first repetition rate defining a period, and wherein said first pulse is generated during a first interval in each period and said second pulse is generated during a second interval in each period, said second interval spaced apart from said first interval, said first and second pulses producing first and second parametric signals responsive to said parameter, said first and second parametric signals being received by a single detector which outputs a composite signal responsive to said first and second parametric signals, said method comprising the steps of:

applying a first demodulation signal to said composite signal to generate a first demodulated output signal, said first demodulation signal comprising at least a first component having a first frequency corresponding to said first repetition rate and having a first amplitude, said first demodulation signal further comprising a second component having a second frequency which is a harmonic of said first frequency and having a second amplitude which has a selected proportional relationship to said first amplitude;

applying a second demodulation signal to said composite signal to generate a second demodulated output signal, said second demodulation signal comprising said first component at said first frequency and said first amplitude and comprising said second component at said second frequency and said second amplitude, at least one of said first and second components of said second demodulation signal having a selected phase difference with respect to the corresponding one of said first and second components of said first demodulation signal; and

lowpass filtering said first demodulated output signal to generate a first recovered output signal responsive to said first parametric signal; and

lowpass filtering said second demodulated output signal to generate a second recovered output signal responsive to said second parametric signal.

4. The method as defined in Claim 3, wherein said selected phase difference is π .

- 1 5. The method as defined in Claim 3, wherein:
2 said first pulse and said second pulse are generally rectangular pulses
3 having a duty cycle, and wherein said rectangular pulses comprise a plurality of
4 sinusoidal components including a fundamental component corresponding to said
5 first frequency and a first harmonic component corresponding to said second
6 frequency, said fundamental component having a fundamental component
7 amplitude and said first harmonic component having a first harmonic component
8 amplitude, said first harmonic component amplitude related to said harmonic
9 component amplitude by a first proportionality value; and
10 said second amplitude of said second component of said first demodulation
11 signal is related to said first amplitude of said first component of said first
12 demodulation signal by a second proportionality value which is approximately the
13 inverse of said first proportionality value.
- 1 6. The method as defined in Claim 3, further including the steps of:
2 sampling said composite signal when neither said first pulse nor said
3 second pulse is active to obtain a sampled signal; and
4 measuring said sampled signal to determine a noise level of said parametric
5 signals.
- 1 7. The method as defined in Claim 3, further including the steps of:
2 performing a transform on said composite signal to generate a spectra of
3 said composite signal;
4 sampling said spectra at a plurality of frequencies other than at
5 predetermined ranges of frequencies around said first frequency and around
6 harmonics of said first frequency;
7 determining an average of the magnitudes of said sampled plurality of
8 frequencies; and
9 comparing said average to a selected threshold to determine whether the
10 average magnitude exceeds said selected threshold.

1 8. A method of demodulating a composite signal generated by applying first
2 and second periodic pulses of electromagnetic energy to a system having a parameter to be
3 measured and by receiving signals responsive to said electromagnetic energy after having
4 passed through said system and being affected by said parameter being measured, said
5 signals received as a composite signal having components responsive to said first and
6 second pulses, said method comprising the steps of:

7 applying a first demodulation signal to said composite signal to generate a
8 first demodulated signal, said first demodulation signal comprising a first
9 component having a first frequency corresponding to a repetition frequency of said
10 first and second pulses and comprising a second component having a frequency
11 which is a harmonic of said first frequency, said first component having a first
12 amplitude and said second component having a second amplitude, said second
13 amplitude having a predetermined relationship to said first amplitude, said
14 predetermined relationship selected to cause said first demodulated signal to have
15 low frequency components responsive only to said first pulse; and

16 lowpass filtering said first demodulated signal to generate a first output
17 signal, said first output signal varying in response to an effect of said parameter on
18 the electromagnetic energy received from said first pulse.

1 9. The method as defined in Claim 8, further including the steps of:

2 applying a second demodulation signal to said composite signal to generate
3 a second demodulated signal, said second demodulation signal having first and
4 second components corresponding to said first and second components of said first
5 demodulation signal, at least one of said first and second components of said
6 second demodulation signal having a selected phase relationship with the
7 corresponding one of said first and second components of said first demodulation
8 signal; and

9 lowpass filtering said second demodulated signal to generate a second
10 output signal, said second output signal varying in response to an effect of said
11 parameter on the electromagnetic energy received from said second pulse.

1 10. The method as defined in Claim 9, wherein said selected phase relationship
2 is a π phase difference.

1 11. A pulse oximetry system, comprising:

2 a modulation signal generator, said modulation signal generator generating
3 a first modulation signal comprising a first pulse which repeats at a first repetition
4 frequency, said first pulse having a duty cycle of less than 50%, said modulation
5 signal generator generating a second modulation signal comprising a second pulse
6 which also repeats at said first repetition frequency, said second pulse having a
7 duty cycle of less than 50%, said second pulse occurring at non-overlapping times
8 with respect to said first pulse, said first and second pulses comprising a plurality
9 of components wherein a first component has a frequency corresponding to said
10 repetition frequency and a second component has a second frequency
11 corresponding to twice said first frequency, said second component having an
12 amplitude which has a first predetermined relationship to an amplitude of said first
13 component;

14 a first transmitter which emits electromagnetic energy at a first wavelength
15 in response to said first pulse;

16 a second transmitter which emits electromagnetic energy at a second
17 wavelength in response to said second pulse;

18 a detector which receives electromagnetic energy at said first and second
19 wavelengths after passing through a portion of a subject and which generates a
20 detector output signal responsive to the received electromagnetic energy, said
21 detector output signal including a signal component responsive to attenuation of
22 said electromagnetic energy at said first wavelength and a signal component
23 responsive to attenuation of said electromagnetic energy at said second
24 wavelength;

25 a first demodulator which multiplies said detector signal by a first
26 demodulation signal and generates a first demodulated output signal, said first
27 demodulation signal comprising a first component having said first frequency and

28 having a first amplitude and comprising a second component having said second
29 frequency and having a second amplitude, said second amplitude having a second
30 predetermined relationship to said first amplitude which second predetermined
31 relationship is inversely proportional to said first predetermined relationship; and
32 a second demodulator which multiplies said detector signal by a second
33 demodulation signal and generates a second demodulated output signal, said
34 second demodulation signal comprising a first component having said first
35 frequency and having said first amplitude and comprising a second component
36 having said second frequency and having said second amplitude, at least one
37 component of said second demodulation signal having a selected phase
38 relationship with a corresponding one component of said first demodulation signal.

1 12. The method as defined in Claim 11, wherein said selected phase
2 relationship is a π phase difference.

1 13. A method of minimizing crosstalk between two signals generated by
2 applying a first pulse and a second pulse to measure a parameter, wherein said first pulse
3 and said second pulse are applied periodically at a first repetition rate defining a period,
4 and wherein said first pulse is generated during a first interval in each period and said
5 second pulse is generated during a second interval in each period, said second interval
6 spaced apart from said first interval, said first and second pulses producing first and second
7 parametric signals responsive to said parameter, said first and second parametric signals
8 being received by a single detector which outputs a composite signal responsive to said
9 first and second parametric signals, said method comprising the steps of:

10 providing said composite signal to an analog to digital converter to produce
11 a sequence of digital values;

12 decimating said sequence of digital values to produce a decimated
13 sequence of digital values;

14 applying a first sequence of demodulation coefficients to said decimated
15 sequence of digital values to generate a first demodulated output signal;

16 applying a second sequence of demodulation coefficients to said decimated
17 sequence of digital values to generate a second demodulated output signal;

18 lowpass filtering said first demodulated output signal to generate a first
19 recovered output signal responsive to said first parametric signal; and

20 lowpass filtering said second demodulated output signal to generate a
21 second recovered output signal responsive to said second parametric signal.

1 14. The method as defined in Claim 13, further comprising the steps of:

2 applying a third sequence of demodulation coefficients to said decimated
3 sequence of digital values to generate a third demodulated output signal; and

4 lowpass filtering said third demodulated output signal to generate a
5 recovered output signal responsive to noise detected by said detector.

1 15. A method of demodulating a composite signal generated by applying a
2 plurality of periodic pulse trains of electromagnetic energy to a system having a parameter
3 to be measured and by receiving signals responsive to said electromagnetic energy after
4 having passed through said system and being affected by said parameter being measured,
5 said signals received as a composite signal having components responsive to said plurality
6 of periodic pulse trains, each of said components corresponding to one each of said pulse
7 trains, said method comprising the steps of:

8 sampling said composite signal using an analog to digital converter to
9 produce a sequence of digital values;

10 decimating said sequence of digital values to produce a decimated
11 sequence of values;

12 providing said decimated sequence of values to a first input of each of
13 plurality of multipliers;

14 providing a plurality of sequences of demodulation coefficients to a second
15 input of each of said multipliers such that each multiplier is provided a unique
16 sequence of demodulation coefficients; and

17 lowpass filtering the output of each of said multipliers such that the output
18 signal of each of said lowpass filters approximately corresponds to one each of said
19 components.

1 16. A pulse oximetry system, comprising:
2 a modulation signal generator, said modulation signal generator generating
3 a first modulation signal comprising a first pulse which repeats at a first repetition
4 frequency, said first pulse having a duty cycle of less than 50%, said modulation
5 signal generator generating a second modulation signal comprising a second pulse
6 which also repeats at said first repetition frequency, said second pulse having said
7 duty cycle of less than 50%, said second pulse occurring at non-overlapping times
8 with respect to said first pulse;
9 a first transmitter which emits electromagnetic energy at a first wavelength
10 in response to said first pulse;
11 a second transmitter which emits electromagnetic energy at a second
12 wavelength in response to said second pulse;
13 a detector which receives electromagnetic energy at said first and second
14 wavelengths after passing through a portion of a subject and which generates a
15 detector output signal responsive to the received electromagnetic energy, said
16 detector output signal including a signal component responsive to attenuation of
17 said electromagnetic energy at said first wavelength and a signal component
18 responsive to attenuation of said electromagnetic energy at said second
19 wavelength;
20 a sampling analog to digital converter which converts said detector output
21 into a sequence of digital values;
22 a decimator which decimates said sequence of digital values to produce a
23 decimated sequence;
24 a first demodulator which multiplies said decimated sequence by a
25 demodulation sequence and generates a first demodulated output signal; and
26 a second demodulator which multiplies said decimated sequence by a
27 second demodulation sequence and generates a second demodulated output signal.
1 17. The apparatus of claim 16 further comprising a third demodulator which
2 multiplies said decimated sequence by a third demodulation sequence and generates a
3 third demodulated output signal corresponding to noise produced by said detector.

1 18. The apparatus of claim 16 wherein said decimator has a decimation rate
2 equal to the number of said samples produced during said duty cycle.

1 19. In a system that includes: a sampling frequency generator generating a
2 sampling frequency f_s ; a detector; a modulation signal generator, said modulation signal
3 generator generating a sequence of pulses having a pulse repetition frequency, said pulses
4 having a duty cycle of Q sample periods of said sampling frequency f_s ; a transmitter which
5 emits electromagnetic energy at a wavelength in response to said pulse, said detector
6 receiving said electromagnetic energy to generate a detector output signal responsive to the
7 received electromagnetic energy, said detector output signal including noise caused by
8 ambient electromagnetic energy detected by said detector; a digital to analog converter
9 which produces digital samples of said detector output signal at said sampling frequency;
10 and a demodulator which demodulates said digital samples to produce a desired output
11 signal, a method for minimizing said noise due to ambient electromagnetic energy in said
12 desired output signal comprising the steps of:

13 identifying all undesired frequency components of said ambient
14 electromagnetic energy detected by said detector;

15 using said undesired frequency components to compute a set of acceptable
16 modulation cycle times T ; and

17 using said acceptable modulation cycle times to select said f_s and said Q
18 using an equation $T=4Q/f_s$.

1 20. A method for demodulating a multi-channel composite signal comprising
2 the acts of:

3 generating a demodulation sequence for a selected channel;

4 providing said demodulation sequence to a first input of a demodulator;

5 providing a sampled composite signal to a second input of said
6 demodulator.

1 21. The method of Claim 20, further comprising the act of decimating an
2 output of said demodulator by a decimation factor R .

1 22. The method of Claim 21, wherein said act of decimating includes the acts
2 of:

3 lowpass filtering; and
4 sample rate compressing.

1 23. The method of Claim 20, further comprising the act of decimating said
2 sampled composite signal before providing said sampled composite signal to said second
3 input of said demodulator.

1 24. The method of Claim 23, wherein said act of decimating includes the acts
2 of lowpass filtering and sample rate compressing.

1 25. The method of Claim 24, wherein said acts of lowpass filtering and sample
2 rate compressing are controlled by an adaptive algorithm.

1 26. The method of Claim 20, further comprising the acts of :
2 decimating in a first decimator said sampled composite signal before
3 providing said sampled composite signal to said second input of said demodulator,
4 wherein said first decimator has a first lowpass filter transfer function and a first
5 decimation rate; and

6 decimating in a second decimator an output of said demodulator,
7 wherein said second decimator has a second lowpass filter transfer function and
8 a second decimation rate.

1 27. The method of Claim 26, further comprising the act of controlling said first
2 lowpass filter, said second lowpass filter, said first decimation rate, and said second
3 decimation rate by an adaptive algorithm.

1 28. The method of Claim 26, wherein a product of said first decimation rate
2 and said second decimation rate is substantially constant.